METHOD AND DEVICE FOR INJECTION OF IONS INTO AN ION TRAP

The invention concerns a method and a device for injection of externally generated ions into an RF quadrupole ion trap after Paul. The invention consists of separating the ions into ion packages within an electrical travelling wave field operated at the frequency of the drive voltage for the ion trap, or at an integral fraction of the same, transporting the ion packages by the travelling wave field to the ion trap, and injecting the ion packages into the ion trap with a favorably selected velocity and at the correct point in time. A slowing-down path at the end of the travelling field allows ions of a greater mass to be injected somewhat earlier than light ions, whereby the simultaneous capture of ions of different masses becomes more favorable.

PRIOR ART

The introduction of mass spectrometric methods into biochemistry, particularly in DNA and protein research, is still impaired by the high consumption of substance needed for these methods. In order to arrive at a useful mass spectrometric result with a few attomols of a substance (1 attomol≈600,000 molecules), it is necessary to reduce substance and ion losses in all steps from ion generation to ion measurement to a minimum. The yield from every step must be optimized.

The generation of ions for mass spectrometric analysis within a vacuum system, or even within an RF quadrupole ion trap, has the disadvantage that the substance molecules must be introduced into the vacuum system with a large surplus. On the one hand, this leads to the danger of condensation of substance molecules on the walls, which results in a build-up of charges on the surfaces and an impairment of function; on the other hand, the ion yield is generally very low for vacuum-internal ionization methods. For this reason, the tendency is more toward generating the ions outside the vacuum system of mass spectrometers, and transferring them by suitable methods into the ion trap.

One example of a vacuum-external ion sources is Electro Spray Ionization (ESI), by which substances of extremely high molecular weights can be ionized with a very high yield at atmospheric pressure. Electrospray is often coupled with modern separation methods such as liquid chromatography or capillary electrophoresis. Ion sources using ionization with Inductively Coupled Plasma (ICP), used for inorganic analysis, also belong to the group of ion sources with vacuum-external ion generation. Finally there is the so-called Atmospheric Pressure Chemical Ionization (APCI) with primary ionization of the reactant gases using corona discharges or beta emitters with electrons emitted at low energy. APCI is used, among other things, for the analysis of pollutants in air and is also especially suitable for coupling mass spectrometry with gas chromatography, liquid chromatography and capillary electrophoresis. Other types of vacuum-external ion sources such as Grimm's hollow cathode discharges or Matrix-Assisted Laser Desorption and Ionization (MALDI) in air are still being analyzed and developed.

According to the previous customary practice, the ions from these ion sources are admitted into the vacuum of the ion trap mass spectrometer with large amounts of ambient gas. For this, fine apertures of about 30 to 300 micrometers in diameter, or 10 to 20 centimeter long capillaries with an inside diameter of about 500 micrometers are used. The excess gas must be removed by differentially operating

pump stages; on commercially available mass spectrometers, two or even three differential pump stages, with a suitable number of chambers, before the main chamber of the mass spectrometer are used. This means that three to four pumps are used. The chambers are joined to one another only by very small apertures, and the ions are passed through these small apertures.

The pressure in the first differential pump chamber on a standard mass spectrometer usually is several millibar, in the second differential pump chamber it is about 10^{-3} to 10^{-1} millibar, if only two differential pump chambers are used, and only in the main vacuum chamber it is 10_{-6} to 10^{-4} millibar. The mass spectrometer is located in the main vacuum chamber. The ions must be passed through the differential pump chambers and the small apertures between the chambers, which results in great ion losses.

To transfer the ions through these chambers more effectively, RF multipole ion guides are often used, which however can only be used at pressures under several 10^{-2} millibar, for otherwise electrical discharges could result. The ion guides can therefore only be used in the second differential pump chamber or in the main vacuum chamber. They are operated to advantage in a pressure range of several 10^{-3} millibar since they then dampen both the radial oscillations and the longitudinal motions of the ions rapidly and thus offer good preconditions for further transport of the ions and their analysis in the mass spectrometer.

The temporary storage of ions in one of the RF ion guides used upstream of the quadrupole ion trap is already a great advancement in respect to the aforementioned optimization of ion utilization. In this way it is possible to temporarily store ions from a continuously operating ion trap in such a way that the quadrupole ion trap is charged with ions in a relatively brief filling time, the ions being temporarily stored during the longer lasting analysis time. In particular, ions in the RF ion guide can be decelerated to thermal energies ("thermalized"), whereby their capture in the quadrupole ion trap is improved. The RF ion guide consists of a cylindrically arranged system of parallel rods to which the two phases of an RF voltage are applied alternately. Quadrupole, hexapole and octopole systems have proven effective for this. Other RF ion guide systems have also become known in the meantime and may be used.

Up to now, however, a critical step has still been the introduction of the ions from the RF ion guide into the quadrupole ion trap. Little is known about the capture process of the ions in the quadrupole ion trap. Our own investigations—both experiments on ion traps as well as computer simulations—have shown that ions can only be captured in a very brief interval of a small percent of the full period of the storage RF (also known as the driving RF). They must be completely decelerated by the opposing field prevalent at the injection time. The deacceleration standstill should be at about the same time as the zero sweep of the storage RF, the ions must therefore be able to be decelerated by the opposing field within a half cycle. Then capture is even possible without the presence of a damping gas. The length of the interval for successful capture depends on the injection energy of the ions and the deceleration gas pressure in the ion trap. A higher pressure for the deceleration gas improves the capture, the capture interval being extended in this way. In the remaining RF cycle, the ions are either reflected by the opposing field at the input to the quadrupole ion trap or else—in more than 50% of the remaining time—accelerated within the ion trap toward the end cap facing the input and thus removed from further utilization.

OBJECTIVE OF THE INVENTION

It is the objective of the invention to find a device and a method with which the ions generated outside the ion trap